# Background and Introduction:

Scoliosis is a pathological curvature of the spine that typically manifests during adolescence and progresses throughout growth. The disease is quantified in terms of the Cobb angle, defined as the greatest angle between the endplates of any two vertebrae in the coronal plane. This angle dictates the course of action in managing the patient’s disease. Patients with Cobb angles less than 20o receive repeated follow-ups to monitor the progression of the curvature. Bracing is used to slow progression for angles between 20o and 40o. Finally, surgical vertebral fusing may be used for angles greater than 40o [Frerich2012]. As such, accurate quantification of the disease is important to prescribe, monitor, and assess the treatment to minimize the disease’s pathology and the cost of treatment. X-ray imaging is currently the gold-standard for scoliosis quantification. Since the disease is quantified in terms of one angle, this information can easily be read from one 2D X-ray image of the back. The health risks of repeated exposure to X-ray radiation throughout adolescence, as progression of the disease is monitored, are well documented [Doody2000, and Schmitz-Feuerhake2011]. These risks have motivated research [Chen2011, Cheung2015a, Cheung2015b, Ungi2014, and Zheng2015] into using spatially tracked ultrasound imaging to quantify scoliosis.

[Chen2011] both verified that the Cobb angle could be accurately inferred from vertebral pedicle locations, and that these pedicles could be accurately located with tracked ultrasound. [Ungi2014] verified that the Cobb angle could be estimated using transverse process locations obtained from tracked ultrasound. Their methods both produced results, within clinically acceptable limits of the ground-truth, radiographically measured Cobb angle. Both of these studies measured phantom models, in-vitro. [Chen2011] made use of a healthy shaped model, while [Ungi2014] used a model exhibiting mild to moderate curvature, with limited vertebral twist or other confounding geometric deformations. Ultrasound images of real patients contain more speckle and artifacts than do those images taken of phantoms. This implies that the landmark data necessary for scoliosis quantification are likely to contain more random noise when collected in a clinical setting.

While [Cheung2015a, Cheung2015b, and Zheng2015] collect in-vivo data to assess their methods of scoliosis quantification, their patients were limited to those having mild to moderate scoliosis, with Cobb angles exclusively less than 45o for [Zheng2015] and less than 30o for [Cheung2015a and Chueng2015b]. Furthermore, they use a special-purpose, wide transducer ultrasound to image the entire width of the spine simultaneously. Such systems are not widespread, and although they facilitate angle measurement, the landmarks they require are not always locatable. In fact, [Cheung2015a, Cheung2015b, and Zheng2015] all either discarded data, or used alternative landmarks in cases where the necessary landmarks could not be found. These studies’ subjects’ Cobb angles are too small to reliably assess the effectiveness of their methods on patients with severe scoliosis. Such patients could have Cobb angles greater than their validated ranges, in addition to modes of deformation such as vertebral twist. Greater spinal deformation could compromise these methods if any landmarks are occluded.

Consequently, quantification of scoliosis from ultrasound-accessible landmarks remains a challenge. The inherent difficulty of interpreting ultrasound can produce landmarks that are inconsistently located, corresponding to noise in the ground-truth landmark locations. Trauma causing landmark destruction or displacement can also result in incomplete landmark sets. Severe coronal curvature and its accompanying deformations can occlude landmarks or orient surfaces such that they do not appear in ultrasound. Because the ribs are parallel and near to the transverse processes, with similar curvature, they can be mistaken for transverse processes. Such a mistake would result in a point which is displaced from its expected ground-truth by an amount dependant on nearby geometry in the anatomy.

# Proposed Work:

We propose to use a neural network approach to estimate the Cobb angle from the locations of patients’ transverse processes. In particular, our focus is on those transverse process locations containing combinations of noise, missing values, and placement errors. We believe that a neural network is well suited to this problem since it involves estimating the function which maps the interdependent set of transverse process coordinates to their angle of maximum coronal curvature. To the best of our knowledge, no work has been done to investigate such a method. Such a neural network should be able to accurately estimate the Cobb angle using a set of 3D anatomic landmark points as input.

# Data and Methods:

For data upon which to train and test the proposed neural network, we have the spatial locations of 124 scoliotic patients’ transverse processes, represented as 3D coordinates. The points were located on   
CT-generated volume models of the patients’ spines. The set sizes vary across patients, as each required only a certain amount of their spine to be scanned for scoliosis assessment. The maximum coronal angle between any two vertebras can be extracted from this data as a ground-truth value for the Cobb angle proxy we wish to estimate. We will preprocess the data by adding random noise, deleting and programmatically displacing various amounts of points. These preprocessing steps simulate likely sources of data error resulting from ultrasound landmark location: basic difficulty in interpreting images, unlocatable landmarks, and misplaced landmarks, respectively.

We will construct a neural network capable of taking sets of various sizes of 3D coordinates as input, and estimating the Cobb angle as output. We will use supervised, backpropagation of error-gradient descent, learning to train the network on roughly 80%, perhaps 100 instances, of the patients’ data. The error to minimize will be the difference between the estimate of our network, and the maximum curvature extracted directly from the original, unperturbed landmark locations. The remaining 20% of the patients’ data will be used to as a testing set to test the network’s curvature (Cobb angle) estimate accuracy.

# Validation:

We will measure the success of our method on the basis of its ability to reproduce the angle of maximum coronal curvature. As the network should accurately estimate the unperturbed data’s curve from the perturbed data, we can measure its error as the difference between its output and the ground-truth angle, as the amount of added noise and proportions of deleted and misplaced points vary. Specifically, we will report the ranges of perturbation values (noise, missing point proportion, and misplaced point proportion) over which the angle of maximum curvature is estimated to within the clinically acceptable [Cobb1948] limits of error, (-/+) 5o.

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